Chapter 3
Foundation and Abutment Treatment

3-1. General

The preparation of the foundation and abutments for an earth or rock-fill dam is a most difficult and important phase of construction; the thoroughness with which it is done is reflected in the performance of the completed structure. It is often difficult or sometimes impossible to correct foundation and abutment deficiencies that show up after construction is well underway or completed. The primary purpose of foundation and abutment treatment is to obtain positive control of under seepage, prepare surfaces to achieve satisfactory contact with overlying compacted fill, and minimize differential settlements and thereby prevent cracking in the fill. Inspection of the work must ensure that the foundation and abutments are stripped to depths sufficient to remove soft, organic, fractured, weathered, or otherwise undesirable materials; depressions and joints in rock surfaces are cleaned and adequately filled; rock surfaces are made relatively smooth and uniform by shaping and filling; subsurface cavities are detected and grouted; and cutoffs extend to suitable impervious materials. During this phase of construction, close liaison must be maintained between construction and design personnel since most discrepancies between design and field construction occur in this portion of the work. Few dams are constructed without encountering some undesirable foundation conditions that were not discovered in exploration for design, such as zones of weathered or fractured rock, cavities, soft soil areas, abandoned pipes or drains, or abandoned stream channels filled with sand and gravel. This is the reason that inspection trenches are generally required beneath the impervious zone of a dam when cutoff trenches are not specified. These inspection trenches provide the means for careful examination of the foundation along the entire length of the dam to ensure that undesirable foundation conditions are detected.

3-2. Clearing, Grubbing, Stripping, and Cleaning

Clearing, grubbing, stripping, and cleaning of areas upon which a compacted earth or rock-fill dam will lie are required to remove those materials having undesirable engineering qualities such as low shear strength, high compressibility, undesirable permeability, or other characteristics which would interfere with compaction operations; and provide a surface favorable for a good bond with the overlying fill. Specifications should provide adequate time for inspection by the Contracting Officer's representative of exposed foundation and abutments. In some cases where abutments will require special treatment, a separate contract for such work is awarded.

a. Soil foundation and abutments.

(1) Clearing consists of removal of all aboveground obstructions, including trees, vegetation, felled timber, brush, abandoned structures, local dams, bridges, and debris. Grubbing includes removal of all objectionable below-ground obstructions or material including stumps, roots, logs, drain tiles, and buried structures or debris. Foundation or abutment soils disturbed during clearing and grubbing operations must be removed. Blasting should be avoided if possible; if unavoidable, explosive charges should be kept as small as possible.

(2) Foundation and abutment stripping generally follow clearing and grubbing operations. Stripping consists of the removal of sod, topsoil, boulders, and organic or foreign materials. Stripping beneath closure sections should be performed in the dry after diversion of the river. Necessary or inadvertent deviation from stripping limits identified in the plans and specifications should be reported to the design office so that effects of the changes can be evaluated. Personnel inspecting stripping operations should be able to identify the materials to be removed. Inspectors should look for soft pockets as well as old sloughs or river meanders that may not have been found during design investigations; the resident geologist can assist in locating such features. Several passes of a heavy roller should be made over the stripped surface to "proof test" the area to reveal any unsuitable materials overlooked during stripping.

(3) The sides of holes and depressions left by grubbing and stripping should be flattened and scarified and the depressions filled with material of the same type and compacted to a density at least equal to that of the surrounding foundation material by the specified method and equipment. Where areal dimensions of depressions are small, power hand tampers are required to compact fill. Final preparation of the foundation surface, immediately prior to placing embankment fill, should include adjusting soil water contents as near optimum as possible, compacting as prescribed for the overlying fill, and scarifying the compacted surface to receive the initial embankment lift.

(4) Compaction of some types of saturated soils in wet foundation areas may do more harm than good. When it is not feasible to dry such areas out, it may be necessary to place a thick initial lift to permit compaction equipment to operate without remolding and disturbing the foundation soil. Also, the weight of compacting equipment operating on the initial lift might be reduced and progressively increased as more lifts are placed. However, this should not

be done for foundation areas under the embankment unless specifically permitted by the plans and specifications or approved by the design office, as the effects of a lightly compacted layer at the base of the dam could adversely affect stability.

(5) Preparation of soil abutments prior to fill placement should be the same as that for soil foundations. To ensure bonding of the embankment to the natural soil of the abutments, it is necessary to remove some of the abutment surface soil. Inspection should confirm that all loose, wet, or soft soils are removed. In addition, abutment slopes should be smooth and as flat as economically feasible at contact with the embankment to improve compaction of fill against the abutment and to minimize the probability of differential settlement causing cracking (paragraph 3-4*a*(5)). Depressions should be filled with concrete or soil compacted at proper water contents to densities equal to or greater than those of the materials to be placed above them in the embankment fill. See paragraph 3-4*a*(2) for discussion of treatment of abutment slopes of clay shales.

b. Rock foundations and abutments.

(1) After all rough excavations of overburden and/or weathered rock have been completed, all grouting is completed, and the surface of the rock foundation is exposed, shaping and cleaning operations should begin. Shaping and cleaning a rough rock foundation are necessary to provide a smooth, uniform, and clean surface against which fill can be compacted. The procedure generally consists of removing large loose rocks, overhangs, and projecting knobs by scaling, handpicking and wedging, and light blasting pressure washing followed by some form of “dental treatment” to fill all holes, cracks, joints, crevices, and depressions. Dental treatment involves cleaning the cavities and backfilling them with concrete, and is discussed in more detail in paragraph 3-4*b*(3). The resident geologist or embankment engineer should inspect and approve this phase of the work.

(2) The final preparation of almost all rock foundations requires hand labor. The use of heavy or tracked vehicles on the final foundation should be avoided, especially if the rock is thinly bedded or badly jointed. Blasting to remove knobs or overhangs may prove more harmful than helpful, and extreme caution must be exercised to prevent the opening of cracks or actual displacement of blocks or rocks that would otherwise provide adequate bearing. It is generally desirable to place concrete fill beneath or around projections if, by so doing, blasting can be avoided. Where concrete fill is used, materials and procedures should be directed towards ensuring good concrete/rock bond; subsequent fill operations should avoid dislocating the concrete. Hand methods involve removal of all loose or “drummy” rock (rock that sounds hollow when struck with a steel hammer or bar), and the scaling down of sloped surfaces to provide an even, uniform slope.

(3) Washing the hard rock foundation surface with water under high pressure and dry brooming to remove loose residue are generally the last step in foundation preparation. This is done to clean the surface to the maximum extent possible and to remove fines that may have worked into seams. All seams or cracks should be cleaned to a depth of at least twice their width. Removal of these fines will facilitate complete filling of seams in subsequent operations (such as dental treatment) taken to prevent seepage. Pressure washing also serves to detect rock projections overlooked during hand excavation which might otherwise work loose during compaction of the first lift or lifts of fill. Washing should be performed to clean from higher elevations to lower elevations.

(4) Particular attention should be given to cleaning openings that cross the axis of the dam. Accumulated water from the washing process must be removed. Small air pumps, hand bailers, or aspirators may be used to empty narrow, water-filled fissures. If the foundation consists of blocky rock with frequent joints, caution must be used to avoid removal of satisfactory foundation material (such as stiff clay in joints) by overzealous pressure washing. When the nature of the rock is such that it could be softened by washing with water, compressed air should be used instead of water. Air pressure is also often used as a final step in cleaning sound rock surfaces. Figure 3-1 shows the rock foundation at DeGray Dam being cleaned with compressed air.

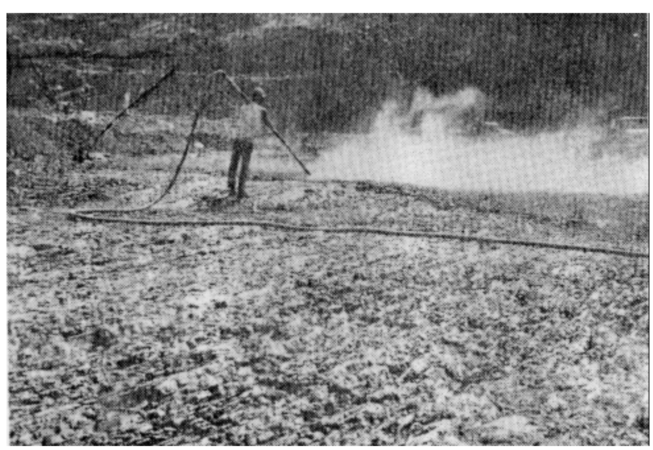


Figure 3-1. Final foundation cleaning using compressed air, DeGray Dam, Arkansas

(5) Where rough and irregular surfaces remain after hand excavation, troughs, pits, and other depressions are filled with concrete to provide a more even surface on which the first layer of the embankment may be compacted. As previously noted, this procedure is termed dental treatment and is discussed further in paragraph 3-4*b*(3). If foundation grouting has been performed, cleanup operations should include removal of any spilled or washed grout that might otherwise conceal surface imperfections and pockets of undesirable material.

(6) Before placing the first layer of embankment material, the cleaned and prepared rock surface should be moistened, but no standing water should be permitted. Moistening the rock surface is recommended instead of using overly wet soil in the first lift to obtain good contact. Use of heavy pneumatic equipment (preferably a rubber-tired roller) is recommended for compacting the first lift on rock surfaces. This will enable the rock surface to be kept intact, especially where the rock surface is irregular or composed of thin beds of alternating hard and soft rock.

(7) Foundations consisting of compaction-type shales and slaking tuffs should be protected from disintegration caused by drying due to exposure to air. The handling of clay shales is discussed in paragraph 3-4*a*(2).

(8) The same degree of care should be exercised in abutment treatment as in foundation treatment. A good bond between the embankment and the abutment is critically important. Areas to be cleaned at rock abutments should include not only those beneath the embankment core but also those beneath transition or filter zones. Within these areas, all irregularities should be removed or trimmed back to form a reasonably uniform slope on the entire abutment with vertical surfaces no higher than 5 ft. Benches between near-vertical surfaces should be of such width as to provide a stepped slope comparable to the slope on adjacent areas but not steeper than 1V on 1H. Overhangs should not be permitted at any locations. Methods of overhang removal are discussed in paragraph 3-4*b*(4).

(9) The treatment of cracks, fissures, and other undesirable conditions in rock foundations and abutments is discussed in paragraph 3-4*b*(2).

3-3. Seepage Control

a. Cutoffs. Foundation cutoffs or core trenches serve as barriers to underseepage. The design of foundation cutoffs is based largely on borings made during field investigations for design. Therefore, the open excavation of a cutoff trench provides the first real look at actual foundation conditions; frequent inspections, particularly by the field geologist and embankment engineer, should be made. Some common types of cutoffs are discussed in the following paragraphs.

(1) Compacted backfill trenches. Backfill compacted into a seepage cutoff trench is one of the most effective construction devices for blocking foundation seepage. Material and compaction requirements are the same as for the impervious section of the embankment. When required by contract specifications, the trench must fully penetrate the pervious foundation and extend a specified distance into unweathered and relatively impervious foundation soil or rock. Treatment (as described in paragraph 3-2*a*) of the exposed surface in the bottom and sides of the trench is essential to ensure firm contact between foundation and backfill. The trench excavation must be kept dry to prevent sloughing of the side slopes and to permit proper backfill placement and compaction. When the water table is near the ground surface, dewatering the excavation is required and is frequently a major expense in cutoff construction. Dewatering and drainage methods are discussed in paragraph 3-5. In any trenching operation, a qualified geotechnical engineer should inspect the construction at regular intervals to monitor stability of the side slopes.

(2) Slurry trenches.

(a) The slurry trench method of constructing a seepage cutoff involves excavating a relatively narrow trench with near-vertical walls, keeping the trench filled with a bentonite slurry to support the walls and prevent inflow of water, and then backfilling with a plastic impervious mixture of well-graded clayey gravel to protect against piping, to reduce seepage, and to minimize consolidation of the backfill material.

(b) The backfill should be a mixture of impervious borrow, sand, gravel, and bentonite slurry (U.S. Army Engineer District, Savannah 1968). The backfill may be a mixture of material excavated from the cutoff trench and other material to provide an acceptable blend.

(c) Depending on the required depth, the excavation may be accomplished with a dragline, backhoe, clamshell, or trenching machine. A trenching machine is limited to depths less than about 40 ft, provided no cobbles exist. Unmodified backhoes are limited to depths less than about 45 ft but with special modification can reach depths of 55 to 60 ft; their main advantage is that they can be used in areas where cobbles exist. Maximum depths of about 100 ft have been achieved with a dragline. Required equipment modifications for excavation to a great depth (with a dragline) include weighting the bucket to overcome the buoyant effect of the slurry and providing heavy-duty bearings and hydraulic systems. A dragline excavating a slurry trench is shown in Figure 3-2.

(d) The specific gravity of the slurry must be high enough to ensure that hydrostatic pressure exerted by the slurry will prevent caving of the sides of the trench and yet not be so high as to limit the depth to which the excavating bucket will operate. Typical values of specific gravity of slurries used in past jobs range from 1.05 to 1.2, with some values as high as 1.5. The slurry level is generally maintained 2 to 3 ft above the groundwater level.

(e) Procedures for cleaning the bottom of the trench, removing sand which settles out of the slurry, continuous control of viscosity and specific gravity of the slurry, and mixing and placing the backfill are critical in achieving successful results. An example of successful slurry trench construction is that at West Point Dam, Chattahoochee River, Alabama and Georgia, in which the bottom of the trench was cleaned with a modified dragline bucket (Jones 1967; U.S. Army Engineer District, Savannah 1968). A scraper blade was attached to the bucket which, when dragged along the bottom of the trench, removed coarser soil particles and some of the finer loose material at the top of the rock. An air jet was used to remove sand, gravel, and other undesirable material from potholes, cracks and crevices; these materials subsequently became entrained in the slurry. Suction and discharge pipes were used to remove contaminated slurry (from the trench), which was cleaned by sending it to shallow sediment ponds along the sides of the trench where the contaminants settled out of suspension. The clean slurry was then placed back into the trench. Mechanical desanders are available and may be desirable or even required for removing sand (from the bottom of the trench) in some situations. The bottom of a trench should be sampled after it has been cleaned to ensure that it is properly free of undesirable material.

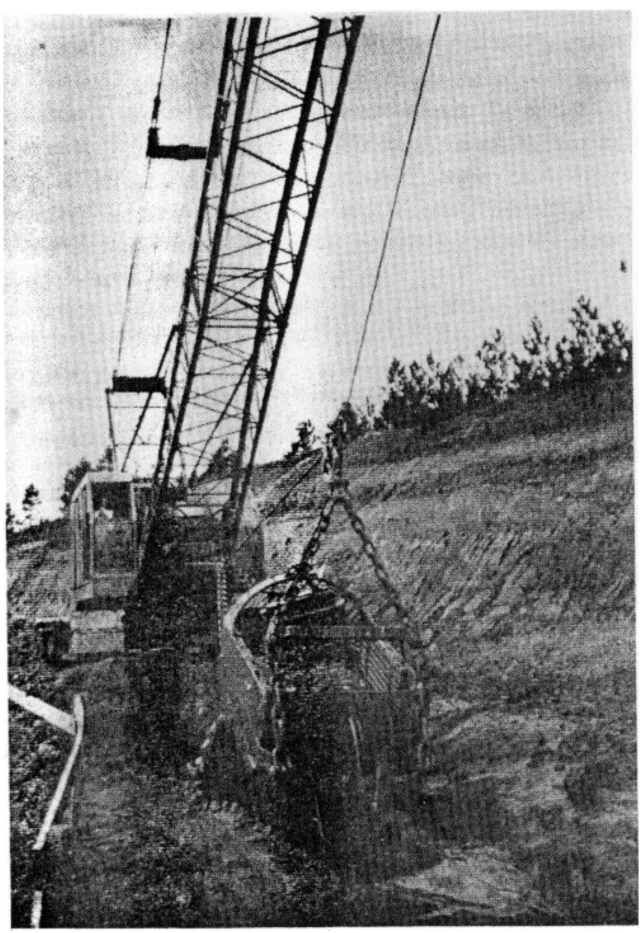


Figure 3-2. Dragline excavation of slurry trench, West Point Dam, Georgia

(f) After the bottom of the trench has been cleaned, backfill is placed in the trench with a clamshell to form a gentle slope parallel to the axis of the trench; backfill is then successively pushed into the trench with a bulldozer and allowed to slide down the slope, intermixing with and displacing the slurry. The slope of the backfill should be flat enough to prevent sliding and sloughing. The trench surface should be observed/inspected as long as possible to detect unusual settlements which might indicate slurry pockets entrapped during the backfilling process. A sketch/schematic of the progressive excavation and backfilling scheme used at West Point Dam is shown in Figure 3-3. The ultimate objective is to achieve a positive cutoff by the combined effects of the backfill and a "filter cake" formed on the sides of the trench by the slurry. Since the integrity of the filter cake after backfill placement cannot be assured, it is recommended that the added benefit of the cake be considered as an additional safety factor with the backfill as the primary element of seepage cutoff.

(g) The slurry trench as a construction technique for forming a cutoff barrier was first used in the United States in the 1940s, and its widespread use began in the late 1960s and early 1970s. Presently, the technique is used routinely although design studies for cutoff walls must be comprehensive and include parameters such as wall depth, thickness, layout, grade, and preparation of the working surface. Design studies must also consider properties of the slurry. Water of adequate quality for slurry mixing must be provided. Typical water quality requirements for bentonite slurry are hardness less than 50 parts per million (ppm), total dissolved solids content less than 500 ppm, organic content less than 50 ppm, and pH of about 7. A satisfactory procedure for the design of slurry trenches and slurry trench construction is given by Winterkorn and Fang (1975).

(3) Grout curtains.

(a) Grouting is the injection by pressure of grout (a mixture of water, cement, and other chemical compounds) into openings (voids, cracks, or joints) in a rock mass. The grout is designed to be injected as a fluid and to stiffen or solidify after injection.

(b) The rock foundation and abutments of most large dams require grouting to reduce seepage and to reduce hydrostatic uplift pressures in dam foundations. Grout curtains are frequently tied into the bottom of cutoff trenches which extend through soil overburden to the rock foundation. Grouting procedures must be tailored to the formation characteristics of the foundation being grouted, and close supervision and inspection are required to obtain satisfactory and economical results. The resident geologist should direct and supervise the inspection of grouting work; he should be experienced in this type of work since many decisions must be made as the work progresses based on judgment and evaluation of results. Successful and economical grouting requires a complete and reliable subsurface investigation to allow determination of the volume which must be grouted. Items which must be determined by the grouting inspector are grout hole location, geometry, length and inclination; injection pressure and rate; grout properties (liquid, transition, set); and necessary degree of improvement in soil properties.

b. Blankets, relief wells, galleries, and toe drains.

(1) Upstream impervious blankets. A horizontal upstream impervious blanket controls underseepage by lengthening the path of underseepage. The effectiveness of the blanket depends on its length, thickness, continuity, and the permeability of the material/soil from which it is constructed. At sites where a natural blanket of impervious soil already exists, the blanket should be closely examined for breaches such as outcrops of pervious strata, root holes, boreholes, and similar (seepage) paths in the foundation which, if present, should be filled or covered with impervious material to provide a continuous impervious blanket. This is especially important in areas where old stream beds may exist. It may be necessary to make additional shallow auger borings during construction to define the extent of breaches, if any, in the natural blanket.

(2) Pressure relief wells. Relief wells are installed along the downstream toe of an embankment to intercept underseepage water and relieve excess uplift pressures that would otherwise develop at the toe of an embankment. Relief of hydrostatic pressure and removal of the associated water volume prevents the transport of soil which might occur in the formation of sand boils and also prevents heaving at the toe. The installation of relief wells is discussed briefly in EM 1110-2-1901 and TM 5-818-5 and in greater detail in EM 1110-2-1914.

(3) Drainage galleries and tunnels. To facilitate foundation and abutment grouting and interception of seepage water, drainage galleries and tunnels are sometimes used in high dams. Drainage tunnels into rock abutments should be examined by a geologist or rock mechanics expert to obtain information on in situ jointing and rock types. Information on the subterranean makeup of the site should be acquired, collated, and interpreted by experienced personnel with geological training for the express purpose of evaluating the site for grouting. The plan for grouting should include design of the location, spacing, depth, and size of grout holes as well as a method to install drain pipes required to block or intercept seepage. The inspector must also be experienced in rock tunneling to ensure satisfactory

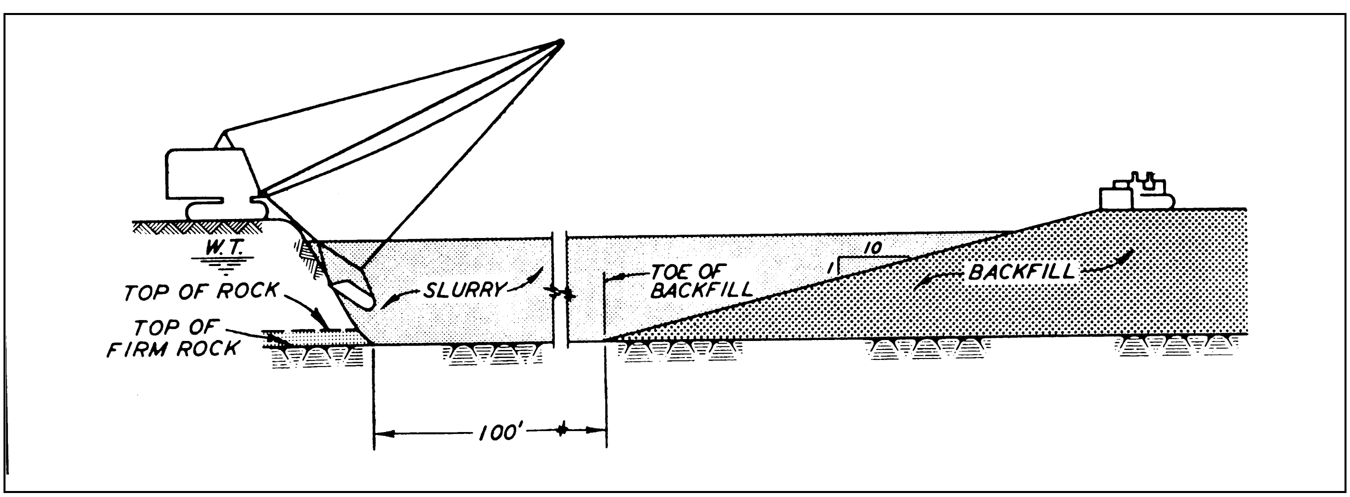


Figure 3-3. Progressive excavation and backfilling scheme for slurry trench construction

installation of rock bolts and other structural support features by plans and specifications. Drainage galleries at the base of a dam or in an abutment of soil or weathered rock are usually concrete-lined tunnels. Inspection of concrete-lined tunnels requires knowledge of concrete placement and backfill practices around concrete structures in addition to knowledge of grouting and seepage control in pervious soils. Inspection of concrete, including proper placement techniques, is thoroughly discussed in the *ACI Manual of Concrete Inspection* (1967). EM 1110-2-2000 also contains information related to the inspection of concrete placement.

(4) Toe drains.

(a) Toe drains collect and facilitate removal of seepage water at the downstream toe of the dam to prevent formation of soft boggy areas and/or boils. Toe drains are generally connected to the horizontal drainage blanket and sometimes to the relief well system to collect and remove seepage water in thin pervious strata in the upper foundation that the deeper relief wells cannot drain.

(b) Toe drains generally consist of a trench containing a perforated collector pipe surrounded by filter gravel with the remainder of the trench backfilled with sand. Particular care must be exercised in placement of the backfill. Unless the sides of the trench are approximately sloped at the angle of repose of the filter material, a wood or steel form must be used to keep the filter layers separated as the backfill is brought up. Additionally, filter materials must be protected from contamination which could result from inwash during a rainstorm. Construction (backfilling) of toe drains in short sections could minimize contamination.

(c) The same control procedures are used for toe drains as those that are used in construction of impervious fill in the main embankment; these are described in Section IV of Chapter 5. Gradation tests on filter materials should be run at least twice each day during placement operations. Stockpiled as well as in-place filter material should be tested. Handling and compaction of the filter material must be closely controlled to avoid segregation and particle breakage.

3-4. Treatment of Unfavorable Conditions

Unexpected unfavorable conditions are frequently discovered during early construction, and may range from undesirable deposits of material not detected in exploratory drilling to adverse seepage conditions that were impossible to predict. Very often, when undesirable materials are found, additional exploration by test pits, borings, or calyx holes is necessary to define the extent of the unexpected deposits and their characteristics. In this way, the impact of a problem deposit can be properly evaluated in relation to the original design. Some common undesirable conditions are discussed in the following paragraphs.

a. Unfavorable soil conditions.

(1) Highly compressible and low strength soils. Organic soils exhibit high compressibility and low shear strength and are generally recognized by their dark color, the presence of organic particles, and often a distinctive “organic” odor. Inorganic clays with high water content also exhibit high compressibility and low shear strength. If an embankment is constructed on a deposit of either highly organic soil or highly compressible inorganic soil, excessive differential settlement could cause cracking of the embankment, or shear failure might occur; if significant deposits of either of these materials are discovered during early construction, their extent should be established and, if it is feasible, they should be removed and replaced with acceptable compacted backfill. If extensive and/or deep deposits of such materials are found, engineering personnel should be consulted to determine if design modifications (such as flattening embankment slopes or adding berms) are required.

(2) Clay shales.

(a) Clay shales are among the most troublesome and unpredictable soils. They are often termed “compaction” or “soil-like” shales if they have been highly overconsolidated by great thicknesses of overlying sediment and have no appreciable cementation. Clay shales tend to slake rapidly when subjected to cycles of wetting and drying; some exhibit very high dry strength, but upon wetting swell and slake profusely, losing strength rapidly. They vary in color from brown to green to black and are often slickensided (a slickenside is a smooth, shiny, striated, discontinuous surface that shows evidence of movement). Problem clay shales can be identified on the basis of slickensides found by breaking undisturbed blocks or chunks apart, and from the speed of slaking during cycles of wetting and drying. Clay shales that are slickensided may be unstable even in relatively flat slopes. Rapidly slaking shales will deteriorate into soft clays with low strength upon exposure to air and water and require protection of exposed surfaces prior to fill placement. Stability in deposits of problem clay shales is further compounded if they are highly fractured or jointed or show evidence of faulting.

(b) Some clay shales also tend to swell or expand considerably when unloaded by excavating overlying material. Expansion may progress deeper into the clay shale deposit with time and cause nonuniform rebound across excavation surfaces. This is caused by stored strain energy that is released with time after overlying materials are removed. Therefore, excavating in clay shales should be completed and backfilled without delay. The last foot or so of excavation into a slaking clay shale should be deferred until just prior to backfill operations in order to minimize the time of exposure of the final clay shale surface. During winter, the depth of cover should be no less than the frost penetration depth; operating in this manner will provide a fresh surface to compact the fill against and eliminate the chance of a soft stratum between the unweathered shale and the fill. This is generally a costly procedure for steep slopes, but becomes more economical for slopes flat enough for equipment to work on.

(c) Only rubber-tired equipment should be used in final excavation, cleanup, and initial fill placement on clay shales to minimize disturbance. Final clay shale surfaces should *not* be scarified prior to covering with fill. If pressure cleaning is required, only air pressure (i.e, no water) should be used.

(d) Various types of coatings have been applied to protect exposed clay-shale surfaces; they include gunite, sprayed asphalt, and other bituminous materials and resin emulsions. Gunite is reliable when reinforced and anchored to the shale, but particular care must be exercised to avoid a drummy condition. This type of protection was successfully used at Waco and Proctor Dams in Texas. Although bituminous coatings and resins have been used successfully, they do not always provide adequate protection for the clay shale. At Waco Dam, an asphalt emulsion membrane used on near-vertical cuts was not always adequate, even with multiple application. Evidence of its inadequacy was that the shale surfaces spalled and slaked. Concrete slabs, whether placed specifically for protective purposes or as slabs for an overlying structure, provide good protection. Exposed surfaces may also be protected by wet mats. Burlap has proven to be an unsatisfactory mat because it is too porous to retain water for any length of time. Maximum allowable exposure time can vary from a few minutes to several hours depending on the characteristics of the shale and the prevailing weather conditions.

(3) Collapsible soils.

(a) “Collapsible” soils are generally soils of low density and plasticity which are susceptible to large decreases in bulk volume when they are exposed to water. Collapsible soils are characterized by bulky grains (in the silt-to-fine-sand grain size) along with some clay. Collapse results from softening of clay binder between larger particles or the loss of particle-to-particle cementation due to wetting. Volume change from collapse occurs rapidly (relative to consolidation) and can be very significant especially if the soil is under high stress. If an embankment is founded on a collapsible soil which is subjected to wetting for the first time, substantial settlement and possibly cracking in the overlying embankment could result. Therefore, unaltered collapsible soils should not be allowed in a dam foundation. If it is not practicable to remove such deposits, they should be treated to break down their structure prior to construction.

(b) Prewetting has been used as a treatment for collapsible soils; the deposits are flooded with water in flat areas where ponding is possible, or by continuous sprinkling on slopes where ponding is not possible. Later, as the embankment is constructed, its weight compresses the foundation soil, causing primary consolidation to take place during construction rather than a sudden and possibly catastrophic foundation collapse when the reservoir is filled for the first time.

(4) Loose granular soils. Loose, water-saturated sands and silts of low plasticity may have adequate shear strength under static loading conditions; however, if such materials are subjected to vibratory loading, they may lose strength to the point where they flow like a fluid. The process in which susceptible soils become unstable and flow when shocked by vibratory loading is called liquefaction, and it can be produced by vibration from blasting operations, earthquakes, or reciprocating machinery. In very loose and unstable deposits, liquefaction can occur as the result of disturbances so small that they are unidentifiable. Loose silt and sand deposits have been compacted by blasting (Layman 1942), vibroflotation, and driving compaction piles; however, the effectiveness of these procedures for deposit densification is not predictable. Vibroflotation has been successfully used in treating limited areas, but it is very expensive. Blasting is generally not effective in densifying loose granular deposits because the vibratory energy produced is of such high frequency.

(5) Steep abutment slopes. Steep abutment slopes of earth tend to increase the possibility of transverse cracks developing in the embankment after construction. During construction, they may become unstable and endanger construction personnel. Slides can occur in clays, sands, and gravel, particularly in slopes subjected to seepage. Slides may damage completed works and require costly repairs. In many cases, it may be necessary to bench the slopes to provide safety against sloughing material and sliding. Frequent inspection should be made by the resident geologist or other experienced personnel to determine whether flattening of specified slopes is required.

(6) Old river channels. Old abandoned river channels filled with pervious or impervious materials are often

encountered unexpectedly during construction. As mentioned earlier, the extent of these deposits is often impossible to establish accurately during the exploratory stages, and in some cases an entire deposit may be missed. Old river channels beneath a dam foundation, filled with course-grained pervious material, would constitute a dangerous open path of seepage. Channel fillings of soft fine-grained materials can cause differential settlements and cracking of the embankment if not removed and replaced with properly compacted material. Where the existence of such deposits has been revealed, additional exploration by borings, test pits, etc., to establish their extent may be necessary. The design engineer can then decide what measures will have to be taken to modify the design or to remove the deposit. An old river channel found during foundation excavation for the core trench at Fall Creek Dam, Fall Creek, Oregon is shown in Figure 3-4.

Figure 3-4. Old River Channel in foundation of Fall Creek Dam, Oregon

b. Unfavorable rock conditions.

(1) Weathered rock. Weathered rock may have undesirable characteristics such as high compressibility, low strength, and high permeability. Removal of weathered rock is generally required for embankments founded on rock to obtain impervious contact beneath the core and to eliminate the possibility of differential settlements and low shear strengths beneath the core and other zones. The weathering of rock is a transitional process; a sharp line of demarcation does not exist between weathered and unweathered zones, and the degree of weathering usually decreases with depth. It may be necessary to excavate deeper in some areas than in others to remove weathered rock. The elevation to solid rock sometimes shown on plans can be used only as a guide. Excavation in abutment and foundation areas being stripped should be inspected by a geologist as work progresses to determine when solid rock is reached.

(2) Open joints and fractures. All open joints, cracks, fissures, and fractures in the foundation rock surface must be filled to prevent erosion or scour of embankment material at the rock contact. A sand-cement mortar is generally used to fill these openings. The mortar is worked into the fractures using a stiff broom, taking care to prevent the accumulation of mortar on unfractured surfaces, where it would not be needed in any event and might be harmful if it cracked or broke off during rolling of embankment fill. The water-to-solids ratio of the mortar should be varied as required to accommodate the conditions encountered. If the rock is closely fractured with fine cracks, the water content may be increased and a fine sand used to permit easy entry of the mortar into the minute seams. If wide, deep cracks are present, a stiffer mortar with coarser sand should be employed to reduce the extent of shrinkage cracking (in the cured mortar). A rock surface after mortar treatment is shown in Figure 3-5.

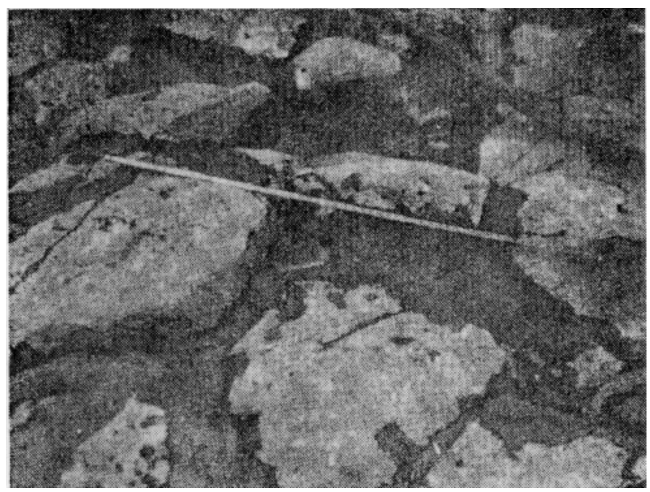


Figure 3-5. Mortar-treated rock surface

(3) Cavities and solution features.

(a) Cavities, potholes, and other voids caused by solution of the rock are dangerous, and field personnel should always be on the lookout for such conditions during foundation preparation. Personnel should be especially alert where a dam is being built on rock susceptible to solution, such as limestone or gypsum. Potholes and cavities exposed or “daylighted” on the foundation surface are usually remedied by dental treatment. Concrete should be thoroughly vibrated or rodded into the voids and its upper surface brought up to the general level of the surrounding rock. Dental treatment serves to smooth up the foundation to reduce compaction difficulties as well as provide a nonerodable impervious seal as a measure of protection against scour of the embankment fill along the rock contact. Figure 3-6 shows a solution channel located directly under the center line of

Figure 3-6. Solution channel, Mississinewa Dam, Indiana

Figure 3-7. Abutment overhang, DeGray Dam, Arkansas

Mississinewa Dam, Indiana, discovered during excavation for the cutoff trench. After extensive exploration to trace its limits, the channel was backfilled with concrete.

(b) The presence of “daylighted” cavities on the foundation surface indicates the possibility of buried cavities or even caverns below grade. Cavities left untreated are highly dangerous, as emphasized by past experience; there have been cases where leakage through underground cavities was so great that it was impossible to fill the reservoir and the dams were eventually abandoned. Hence, any indication of underground cavities (such as sink holes, disappearance of surface water, etc.) should be reported so that further exploration may be undertaken if required. If an extensive network of solution cavities is found, extensive grouting may be required to ensure the imperviousness of the foundation.

(4) Overhangs and surface depressions. Overhangs and other irregularities in the rock surface of an abutment or foundation must be corrected. An abutment overhang at DeGray Dam, Arkansas, is shown in Figure 3-7. Overhangs should be removed by drilling and blasting with care so as not to disturb the adjacent sound rock. Line drilling and blasting (or blasting with presplitting) have been used successfully to form a relatively smooth surface (EM 1110-2-3800). Presplitting has generally given better results than line drilling for a variety of rock types. Figure 3-8 shows the left abutment at J. Percy Priest Dam, Tennessee, formed by the presplitting method. Concrete dental treatment can be used to fill depressions created by blasting and to remedy some types of overhangs. An example of the use of dental concrete to eliminate an abutment overhang is shown in Figure 3-9. Tamping of soil under overhangs instead of removal or dental treatment must not be permitted. Surface

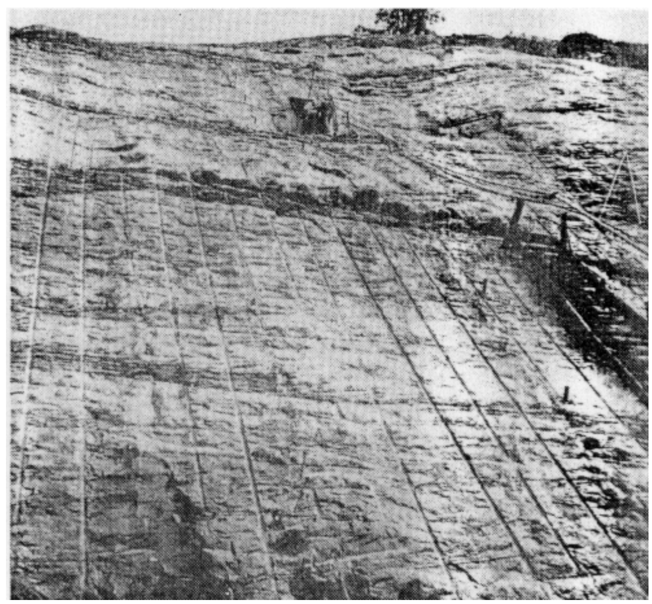


Figure 3-8. Presplit abutment, J. Percy Priest Dam, Tennessee

depressions are generally filled with select impervious borrow using heavy mechanical hand tampers to even up the foundation surface in preparation for the first lift of material to be compacted by heavy roller equipment. If the rock is very irregular, it may be more economical to cover the entire area with a concrete slab. It should be noted that a gently undulating rock surface is desirable, and only when surface depressions interfere with compaction of the first lift should concrete backfilling be required.

(5) Springs. Springs, often encountered in rock foundations and abutments, are simply groundwater sources

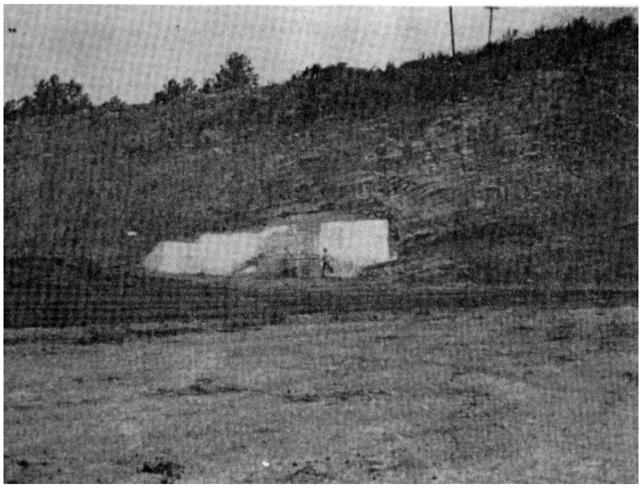


Figure 3-9. Abutment overhang after concreting

Figure 3-10. Seepage from spring in abutment at Green River Dam, Kentucky

seeping to the ground surface driven by artesian pressure. Attempts to place impervious fill over springs issuing from joints or rock fractures will result in extremely wet soil in the vicinity of the spring which is impossible to properly compact. Depending on the flow rate and pressure driving the spring, seepage will continue through the wet soil, creating an uncompacted weak zone of increasing size if fill placement is continued without properly removing this source of water. The zone created around an improperly controlled spring is a very dangerous situation which will cause problems both during construction and over the life of the embankment. Where the water is under a low head and has a single point of issue, a standpipe can usually be installed. A corrugated metal pipe of a diameter depending upon the size of the spring is placed over the spring area, and a damp mixture of quick-setting cement, sand, and gravel is packed around the standpipe base. Earth is then compacted around the outside of the pipe at the base. The water is kept pumped down within the standpipe until an impervious seal is obtained and enough pipe sections have been added to retain the head of water in the pipe. The pipe is then filled with vibrated concrete or grout, and construction of the fill continued upwards and across the top of the plugged pipe by conventional methods. The area is then examined for evidence of new springs, which often appear after an old spring is plugged. This procedure can also be used for springs on the abutment when the fill reaches the same elevation as the spring. While filling operations are progressing below the spring, a small pipe can be grouted into the source of seepage and discharged away from the fill as a temporary measure. This procedure was used at Green River Dam, Kentucky, to eliminate seepage from the abutment spring shown in Figure 3-10. If the springs are not fully localized in area, more extensive methods as described in paragraph 3-5 may be required.

3-5. Dewatering and Drainage of Excavated Areas

Inadequate control of groundwater seepage and surface drainage during construction can cause major problems in maintaining excavated slopes and foundation surfaces and in compacting fill on the foundation and adjacent to abutment slopes. Plans and specifications seldom contain detailed procedures for dewatering and other drainage control measures during construction, and the contractor is responsible for dewatering systems adequate to control seepage and hydrostatic uplift in excavations, and for collection and disposal of surface drainage and seepage into excavations. Inspections and observations must ensure that dewatering and drainage control systems are installed correctly and are functioning properly.

a. Dewatering.

(1) Potential troubles can often be detected in early stages by visual observation of increased seepage flow, piping of material from the foundation of slopes, development of soft wet areas, uplift of excavated surfaces, lateral movement of slopes, or failure of piezometer water levels to drop sufficiently as pumping is continued. Water pumped from dewatering systems must be observed daily at the discharge outlet; if the discharge water is muddy or contains fine sand, fines are being pumped from the foundation. This can be observed by obtaining a jar of the water and observing sediment settling near the bottom. The pumping of fines from the foundation can cause internal erosion channels or piping to develop in the embankment structure; if this happens it is crucial that corrective measures be

taken. Wells or wellpoints from which fines are being discharged must be sealed and replaced with wells having adequate filters. Piezometers should be installed with dewatering systems to monitor drawdown levels in the excavated area. Piezometers should be read daily and the readings plotted to enable continuous evaluation. Daily pumping records should also be kept and evaluated to determine the quantity of water removed by dewatering systems and sump systems. These records are valuable for detecting inadequate seepage control and for evaluating claims by the contractor of changed conditions with respect to the plans and specifications. A detailed description of various types of dewatering systems, installation procedures, and performance evaluation is given in TM 5-818-5. A sketch of a single-stage wellpoint dewatering system is shown in Figure 3-11a, and a sketch of a multistage dewatering system with provisions for drainage of surface water is shown in Figure 3-11b. The two-stage wellpoint system used to dewater the core trench at Carlyle Dam, Illinois, in the St. Louis district is shown in Figure 3-12.

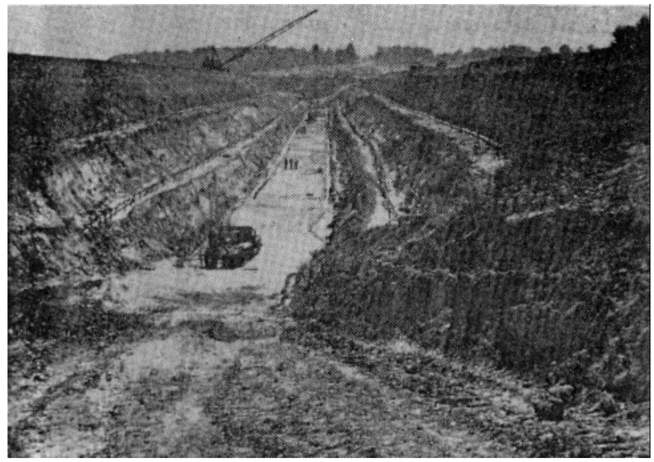


Figure 3-12. Core trench at Carlyle Dam, Illinois, with two-stage wellpoint dewatering systems on each slope

(2) Failure of the dewatering system can result in extremely serious problems, often requiring extensive and expensive remedial work. In excavations bottoming in impervious material, unchecked artesian pressure in underlying pervious strata can cause heaving of the excavation bottom. If the impervious stratum ruptures under these pressures, boils (violent emission of soil and water) will develop, causing the loss of the underlying foundation material and thereby endangering the entire structure. Figure 3-13 shows sand boils that developed at Friars Point, Mississippi, landward of a levee during a high river stage. Similar boils could develop on the bottom of an excavation from excessive artesian pressures in the underlying strata. Failure of excavation slopes may also occur because of excessive artesian pressures. In order to prevent failure of the dewatering system, all power sources should have standby gas or diesel-powered pumping or generating equipment, and standby pumps should be available.

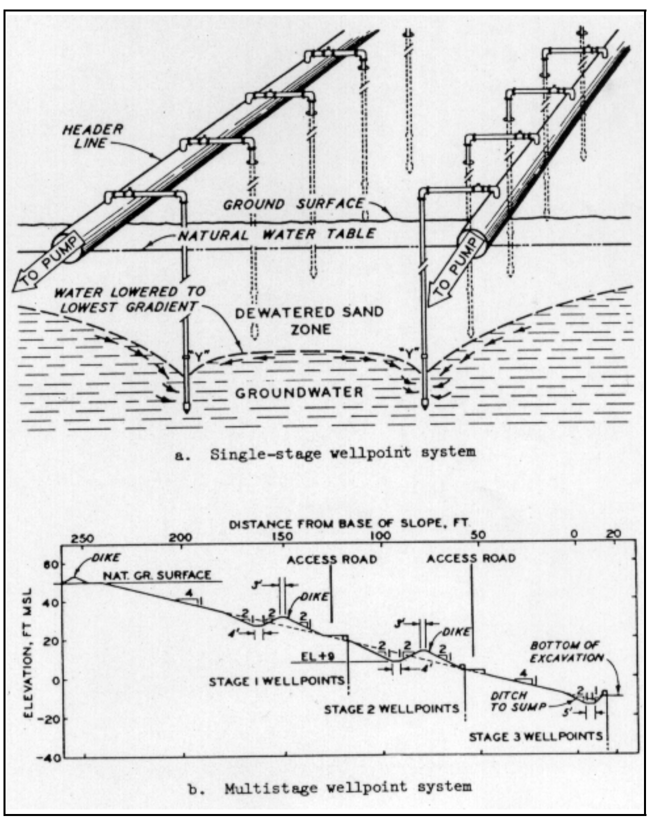


Figure 3-11. Dewatering systems

b. Sumps and ditches.

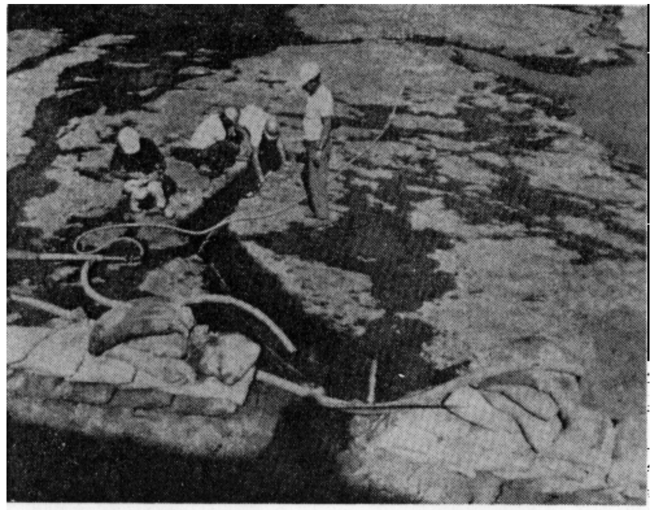
(1) When an excavation such as a cutoff trench is extended to rock or to an impervious stratum, there will usually be some water seeping into the excavation and/or

Figure 3-13. Sand boils at Friars Point, Mississippi

"wet spots" in the bottom of the excavation, even with deep wells or wellpoint systems in operation. Water seeping into the excavation from the upstream and downstream slopes of a long cutoff trench can usually be captured by excavating narrow longitudinal ditches or drainage trenches at the intersection of the slopes and the bottom of the excavation (see Figure 3-11b), or by forming such trenches with sandbags, with sumps located as necessary for pumping the water out. If the bottom of the excavation will still not dry out, smaller ditches can be cut through the problem areas and sloped to drain to the side trenches.

(2) To keep the bottom of the cutoff trench dry while placing backfill, the drainage ditch system can be filled with gravel so that the system can continue to function even after being covered with soil. These gravel-filled ditches should constitute only a very small portion of the overall area being drained to preclude the necessity of later grouting large portions of the bottom of the cutoff trench containing gravel. The surface of the gravel can be covered with a layer of heavy felt paper, burlap, or plastic sheeting, or by a layer of stiff concrete to prevent migration of fines from the fill material. The ditches are blocked at the ends of the excavation by means of concrete plugs. Riser pipes are brought up from each sump (low point in the ditch) with the result that water can be pumped from one or more of the riser pipes as necessary, with the remaining riser pipes serving as vent pipes.

(3) After the backfill is brought to a height that will counteract the hydraulic head, the gravel-filled ditches are grouted. Cement grout is introduced under gravity through one riser pipe with the vent pipes serving as an escape for air and water in the gravel. When grout issues from the vent pipes, the vent pipes are shut off and a slight pressure is maintained in the system until the grout has set. After grouting, normal fill placement operations are continued. If only one sump is used in the drainage system, a vent pipe will have to be installed at an appropriate location before backfilling starts.



a. Drainage trench dug along water-producing crack in shale

b. Collection point for drainage trenches

Figure 3-14. Foundation drainage system at Laurel Dam, Kentucky

(4) Figures 3-14a and 3-14b show the drainage system successfully used at Laurel Dam, Kentucky, to remove localized flow cracks in the shale. The system provided a dry foundation for impervious material. Figure 3-14a shows a trench dug along a water-producing crack in the shale. A perforated collector pipe was placed in the trench with a vent hose and grout pipe attached. The collector pipe was surrounded with stone and the remaining portion of the trench filled with concrete. Water volume from various collector pipes discharged into a collection box from which a single pipe carried the water to a pump located in a 60-in. corrugated metal pipe (CMP) sump (see Figure 3-14b). The vent hoses, grout, pipes, and CMP were extended as the fill was brought up. After 20 to 30 ft of embankment fill had been placed, the collector pipes were grouted and the CMP was filled with -3-in. stone and grouted.

(5) In many cases where a dewatering system is being used, a 4- to 5-ft-high impervious blanket placed at the toe of the slope will prevent the minor seepage flow that otherwise might occur and will therefore provide a dry bottom.

c. Surface erosion. Surface erosion may present problems on slopes cut in silts, fine sands, and lean clays.

Eroded material will wash down and fill in the excavation below the slope. The slope itself will be left deeply scoured and rutted, making it necessary for costly smoothing operations to be performed before the fill can be placed against it. Figure 3-15 shows surface erosion on an unprotected excavation at Kaskaskia Dam, Illinois. The best way to combat surface erosion of temporary excavation slopes is to backfill as soon as possible, thus cutting down on exposure time. This often cannot be done, however, and it becomes necessary to take other measures. Grass cover on the slopes is a good means of preventing surface erosion if it can be readily established and if the slopes are to remain open for a season or two. Other slope protection measures such as rip-rap or asphaltic treatment are rarely justified for construction slopes. Thus, it is necessary to keep as much water off the slope as possible. Most slopes can withstand rain falling directly on them with only minor sloughing. Perimeter ditches and/or dikes (see Figure 3-11b) at the top of the slope are needed to carry other surface waters away from the excavation if surface waters outside the excavation would otherwise run into it. Ditches may be needed at several elevations along the excavation slopes to catch surface waters, as shown in Figure 3-11b.

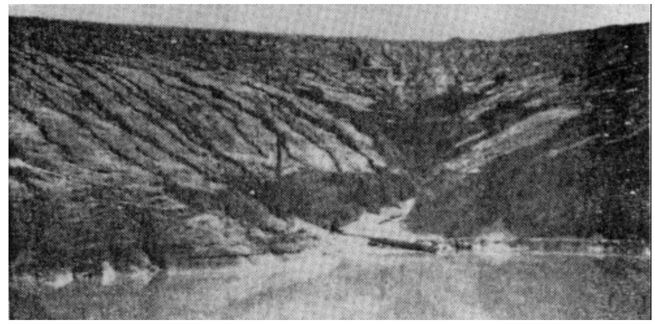


Figure 3-15. Surface erosion of unprotected construction slope of Kaskaskia Dam, Illinois

d. Other seepage control measures. Other means of stabilizing excavation slopes and preventing seepage from entering an excavation (such as electro-osmosis, freezing, sheet-piling, and grouting) have been used for structure excavations. These methods are not economically feasible for extensive foundation excavations for dams but might be used in structures where conventional dewatering methods are not suitable for various reasons.